Numerical Study of Urban Heat Islands in Sofia and Sendai with Present, Past, and Potential Natural Vegetation Land Use

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Abstract

This study has a purpose to examine the impact of urbanization and the effect of urban heat island (UHI) on the surface air temperature distribution in Sofia, Bulgaria and Sendai, Japan during the 150-year period. This impact is evaluated using the Weather Research and Forecasting (WRF) model with a horizontal resolution of 1-km in three separated months of July (2011-2013) for Sofia City in four land use cases: past land use (URB1878), present land use with anthropogenic heat (AH) release (URB2012), present land use without AH release (LU2012) and urban land cover replaced by potential natural vegetation (PNV). For Sendai City, ten separated months of February and August (2000-2009) in four land use case was simulated as follows: past land use (1850s), present land use with AH release (2000s), present land use without AH release (LU2000s) and PNV.

Firstly, the results from the observational data in Sofia City show that the surface air temperature at the central station of the city at 0600 LST is 1.60 –2.40 ºC higher compared to those of the surrounding stations. However, at 1500 LST, this temperature difference decreases to around 0.50 ºC. The model results from the control case (URB2012) were compared with the observations. The WRF model accurately reproduces the observed temperatures in Sofia City and its surrounding stations with mean biases from -0.64 ºC to 1.33 ºC. In the URB1878 land use case, the UHI is negligible because of very small urban area of Sofia City. This case gives nearly the same surface air temperatures as experiments using the PNV. The simulated results of the monthly mean temperatures between the URB2012 and URB1878 land use cases show a significant nocturnal (2000–0700 LST) average temperature increase of 3.20 ºC at the central part of Sofia City, while the land use changes between the URB1878 and LU2012 cases contribute to increasing the nighttime temperatures by 2.60 ºC (81%). Furthermore, the simulated results between the URB2012 and LU2012 land use cases indicate that the AH releases cause temperature increases of only 0.60 ºC (19%) at the central part of the city. The results suggest that the main reason for increasing the surface air temperature in the central part of Sofia City is the land use changes between 1878 and 2012.

Secondly, the results from the 2000s land use case were verified against observations in Sendai City. The results show that the WRF model reasonably well reproduces the diurnal variation of the observed surface air temperatures in the 2000s land use case in Sendai City and five additional stations in the Miyagi prefecture. The model mean biases range from −0.44 to −1.50 °C

in February (10-year average) and from −0.29 to −1.18 °C in August (10-year average). Moreover, the impacts of urbanization on the temperature distribution in and around Sendai City are evaluated. For the 1850s land use case, the very small urban area of Sendai City led to a negligible UHI. Furthermore, the 1850s land use case yields nearly the same surface air temperatures as experiments using PNV. Comparing the simulated monthly mean surface air temperatures in the central part of Sendai City between the 1850s and 2000s land use cases, we found that the monthly mean temperature for February in the 2000s is 1.40 °C higher than that in the 1850s, whereas that for August is 1.30 °C. Similarly, we found considerable nocturnal (1800–0500 JST) average surface air temperature increases of 2.20 °C in February and 2.00 °C in August. Furthermore, the comparisons between the 2000s, LU2000s and 1850s cases showed that the land use changes contribute to increasing the nocturnal temperatures by 0.80 and 1.10 ºC (36 and 55%) in February and August, while the AH releases cause temperature increases by 1.40 and 0.90 ºC (64 and 45%) respectively at the central part of Sendai City.

Keywords: urban heat island; urbanization; potential natural vegetation; land use change; anthropogenic heat; Weather Research and Forecasting model; Sofia, Bulgaria; Sendai, Japan